Factors affecting the consumption of fuel and energy resources during the construction of monolithic buildings

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Abstract. The organization of work at the construction site is regulated by the calculated indicators of the consumption of fuel and energy resources. In the process of solving the problems of organizational and technological modeling, factors are determined that, to varying degrees, affect the reduction in the consumption of fuel and energy resources during construction and installation works. The purpose of the study is to determine the factors that affect the reduction of fuel and energy resources at the stage of organizational and technological design. We used the method of expert assessments, method of a simplified approach to average energy costs for individual types of consumers for a certain period of work, specific indicators of the consumption of certain types of resources in a wide range are used. When developing calendar plans and building master plans as part of the organizational and technological documentation, a methodology for summarizing and consolidating a number of indicators is used, most of which have no quantitative measurement. As the results, the variation coefficients are determined for the factors to ensure the activities of construction organizations in the field of energy conservation and energy efficiency.

1 Introduction

In the studies of the most cases, to determine the energy resources at the construction stage, a simplified approach is used to average energy costs for individual types of consumers for a certain period of work. In this case, specific indicators of the consumption of certain types of resources in a wide range are used. So, for example, reference data on energy consumption for heating reinforced concrete are in the range of 20-70 kW / m³. Many other specific indicators are determined in a similar way.

In this regard, the tasks to ensure the activities of construction organizations in the field of energy conservation and energy efficiency should be based on updated reference and regulatory literature, as well as systematized data on energy conservation technologies used at construction sites, providers of services and products in the field of energy conservation and energy efficiency, rational terms and conditions of work. This information is compiled and analyzed by the expert community.

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2 Methodology

The study identified factors that affect the reduction of fuel and energy resources at the stage of organizational and technological design. The following factors were taken as factors affecting the consumption of fuel and energy resources in the construction industry:

C₁ - calendar terms and shift of construction and installation works;

C₂ - selection of a set of technological equipment to ensure the quality and intensity of construction and installation works (concrete heating, etc.);

C₃ - duration of work;

C₄ - selection of equipment for construction and installation works;

C₅ - selection of a set of machines and mechanisms;

C₆ - engineering support for the infrastructure of the construction site.

Using qualimetric research methods, it is possible to determine the relative importance of a factor on the basis of an expert survey and generalization of the views of an expert group.

The practice of an expert survey showed that its reliability significantly depends on the number of factors evaluated. The more factors to be evaluated, the greater the totality of factors that experts attach equal importance to. With the increase in the number of factors being evaluated, experts are becoming increasingly indifferent in their judgments. Given this, we determine the number of various factors affecting the reduction in the consumption of fuel and energy resources, equal to six.

The minimum number of experts should be no less than the number of evaluated objects, in our task, at least six. We assign the number of experts equal to 20. The results of expert evaluations are shown in the table 1.

Table 1. The expert assessment of factors affecting the consumption of fuel and energy resources in the construction of monolithic buildings.

Expert No	Factors affecting the consumption of fuel and energy resources					
	C ₁	C ₂	C ₃	C ₄	C ₅	C ₆
1	100	40	60	30	20	35
2	100	75	100	40	50	80
3	100	60	80	30	20	70
4	100	40	60	10	20	50
5	100	50	70	80	30	50
6	100	20	40	80	70	60
7	100	40	80	50	60	20
8	100	70	80	50	45	65
9	100	60	90	20	20	50
10	100	80	60	40	20	55
11	100	70	30	80	50	40
12	100	40	70	50	90	20
13	100	50	80	60	80	100
14	100	70	60	30	20	10
15	100	80	90	30	20	50
16	100	100	80	50	40	70
17	100	70	50	20	40	80
18	100	20	80	60	50	40
19	100	60	90	20	30	80
20	100	70	60	80	30	95

An indicator of a generalized opinion can be the average statistical value of the assessment of a certain factor, determined in points or in the form of weighting factors.

Score of the n-th factor in points:

$$P = \sum_{k=1}^K \frac{C_{kn}}{K}, \quad (1)$$

where C_{kn} is the assessment by the K-th expert of the importance of the nth factor;
 K is the number of experts.
 Estimates of the n-th factor:

$$\bar{\beta} = \sum_{k=1}^K \frac{\beta_{kn}}{K}, \quad (2)$$

where β_{kn} is the normalized estimate given by the Kth expert for the nth factor.

The degree of consistency of expert opinions on all types of factors (object of examination) is estimated by the coefficient of concordance:

$$\omega = \frac{12 \sum_{n=1}^N (S_n - \bar{S})^2}{K^2 N(N^2 - 1) - K \sum_{k=1}^K T_k}, \quad (3)$$

where S_n is the sum of ranks assigned by experts to the nth factor;

R_{kn} - rank of the nth factor assigned by the K-th experts;

$\bar{S}$ is the average value of the sum of ranks;

$$T_k = \sum_{m=1}^{M_k} (t_{km}^3 - t_{km}), \quad (4)$$

where t_{km} is the number of identical ranks of the mth type in the estimates of the Kth expert;

M_k - the number of factors with matching ranks in the estimates of the K-th expert.

The concordance coefficient varies from zero to unity, and $\omega = 1$ corresponds to the full agreement of expert opinions.

The significance level of the concordance coefficient is used as a quantitative assessment of the degree of this randomness. This level is found in the tables on the basis of a comparison of the number of degrees of freedom ($N - 1$) with the value χ^2 (Pearson criterion), calculated by the formula:

$$\chi^2 = \frac{12 \sum_{n=1}^N (S_n - \bar{S})^2}{KN(N-1) - \sum_{k=1}^K T_k / (N-1)}, \quad (5)$$

If the significance level found in this way is small enough, then the consistency of expert opinions, characterized by this coefficient of concordance, is not accidental. The methodological principles of the organization of reengineering in the construction were determined, given the experience of previous studies [1-8].

3 Results and discussion

The algorithm of the expert assessment method includes the following main steps:

Stage 1 - Determination of normalized estimates given by experts according to the formula (1):

$$\beta_{1,1} = \frac{C_{1,1}}{C_{1,1} + C_{1,2} + \dots + C_{1,n} \dots + C_{1,6}} = \frac{100}{100 + 40 + 60 + 30 + 20 + 35} = 0,351$$

$$\beta_{1,2} = \frac{C_{1,2}}{C_{1,1} + C_{1,2} + \dots + C_{1,n} \dots + C_{1,6}} = \frac{40}{100 + 40 + 60 + 30 + 20 + 35} = 0,140$$

In the same way, the ratings are normalized for other experts; the calculation results are shown in the table 2.

Table 2. The normalized expert ratings.

β	1	2	3	4	5	6
1	0.351	0.140	0.211	0.105	0.070	0.123
2	0.225	0.169	0.225	0.090	0.112	0.180
3	0.278	0.167	0.222	0.083	0.056	0.194
4	0.357	0.143	0.214	0.036	0.071	0.179
5	0.263	0.132	0.184	0.211	0.079	0.132
6	0.270	0.054	0.108	0.216	0.189	0.162
7	0.286	0.114	0.229	0.143	0.171	0.057
8	0.244	0.171	0.195	0.122	0.110	0.159
9	0.294	0.176	0.265	0.059	0.059	0.147
10	0.282	0.225	0.169	0.113	0.056	0.155
11	0.270	0.189	0.081	0.216	0.135	0.108
12	0.270	0.108	0.189	0.135	0.243	0.054
13	0.213	0.106	0.170	0.128	0.170	0.213
14	0.345	0.241	0.207	0.103	0.069	0.034
15	0.270	0.216	0.243	0.081	0.054	0.135
16	0.227	0.227	0.182	0.114	0.091	0.159
17	0.278	0.194	0.139	0.056	0.111	0.222
18	0.286	0.057	0.229	0.171	0.143	0.114
19	0.263	0.158	0.237	0.053	0.079	0.211
20	0.230	0.161	0.138	0.184	0.069	0.218

Stage 2 - Determination of the average values of the weighting coefficients for each factor by the formula (2):

$$\bar{\beta}_1 = \frac{\beta_{1,1} + \beta_{2,1} + \dots + \beta_{20,1}}{K} = \frac{0,351 + 0,225 + \dots + 0,230}{20} = 0,275$$

$$\bar{\beta}_2 = \frac{\beta_{1,2} + \beta_{2,2} + \dots + \beta_{20,2}}{K} = \frac{0,140 + 0,169 + \dots + 0,161}{20} = 0,157$$

In the same way, the average values of the weighting coefficients are determined for the remaining factors; the calculation results are presented in table 3.

Stage 3 - Determination of standard deviations of the weighting factors:

$$\sigma_n = \sqrt{\frac{\sum_{k=1}^K (\beta_{kn} - \bar{\beta}_n)^2}{K}} \quad (6)$$

$$\sigma_1 = \sqrt{\frac{(\beta_{1,1} - \bar{\beta}_1)^2 + \dots + (\beta_{20,1} - \bar{\beta}_1)^2}{K}} = \sqrt{\frac{(0,351 - 0,275)^2 + \dots + (0,230 - 0,275)^2}{20}} = 0,039$$

$$\sigma_2 = \sqrt{\frac{(\beta_{1,2} - \bar{\beta}_2)^2 + \dots + (\beta_{20,2} - \bar{\beta}_2)^2}{K}} = \sqrt{\frac{(0,140 - 0,157)^2 + \dots + (0,161 - 0,157)^2}{20}} = 0,051$$

In the same way, the standard deviations of the weight coefficients for the remaining factors are determined, the calculation results are presented in table 3.

Stage 4 - Determination of the coefficient of variation for each factor:

$$\vartheta_n = \frac{\sigma_n}{\bar{\beta}_n} \quad (7)$$
$$\vartheta_1 = \frac{\sigma_1}{\bar{\beta}_1} = \frac{0,039}{0,275} = 0,141$$
$$\vartheta_2 = \frac{\sigma_2}{\bar{\beta}_2} = \frac{0,051}{0,157} = 0,034$$

In the same way, the variation coefficients are determined for the remaining factors. The calculation results are presented in table 3.

Table 3. The results of the calculations.

View	1	2	3	4	5	6
$\bar{\beta}_n$	0.275	0.157	0.192	0.121	0.107	0.148
σ_n	0.039	0.051	0.046	0.054	0.052	0.053
ϑ_n	0.141	0.324	0.239	0.446	0.483	0.361

Stage 5 - Transition from the table of marks in points to the ranking matrix.

The transition procedure consists in assigning the first number (rank) to the factor that has the highest score in points, and the last to the factor with the lowest score. Factors with the same scores are assigned the same rank.

So, for the first factor (see table 1), instead of the points, ranks can be put down (table 4).

Table 4. The rank matrix.

Expert No K	R _{K1}	R _{K2}	R _{K3}	R _{K4}	R _{K5}	R _{K6}
1	1	3	2	5	6	4
2	1.5	4	1.5	6	5	3
3	1	4	2	5	6	3
4	1	4	2	6	5	4.5
5	1	4.5	2	6	5	3
6	1	6	5	2	3	4
7	1	5	2	4	3	5
8	1	3	2	5	6	4
9	1	3	2	5.5	5.5	4
10	1	2	3	5	6	4
11	1	3	6	2	4	5
12	1	5	3	4	2	6
13	1.5	6	3.5	5	3.5	1.5
14	1	2	3	4	5	6
15	1	3	2	5	6	4
16	1.5	1.5	3	5	6	4
17	1	3	4	6	5	2
18	1	6	2	3	4	5
19	1	4	2	6	5	3
20	1	4	5	3	6	2

Moreover, two cases are possible:

1) If the sum of certain ranks coincides with the sum of a natural series of numbers, then certain values of ranks are not subject to change. In our task for the first expert, the sum of the ranks coincides with the sum of the natural series of numbers, therefore, the series is entered in table 4 without changes:

$$\sum_{n=1}^N R_{1n} = 1 + 3 + 2 + 5 + 6 + 4 = \sum_{i=1}^N R_{Hi} = 1 + 2 + 3 + 4 + 5 + 6 = 21$$

2) If the sum of certain ranks does not coincide with the sum of a natural series of numbers, then the same rank is assigned the same rank equal to the arithmetic average of the corresponding numbers of the natural series. So, in the second expert, the first factor and the third factor are evaluated equally, at 100 points. In the natural number series, this will correspond to the numbers 1 and 2. Therefore, the first and third factors should be assigned the same rank, which is equal to:

$$R_{21} = R_{23} = (1+2)/2 = 1,5$$

The matrix of ranks in which the sum of the ranks for each expert is equal to the sum of the natural series of numbers is called normalized. The sum of a natural series of numbers can be determined by the formula:

$$\sum_{n=1}^N R_{Hi} = \frac{N(N+1)}{2} = \frac{6(6+1)}{2} = 21$$

1) Using the formula (4), we determine the sums of matching ranks for each expert:

$$T_1 = t_{1,1}^3 - t_{1,1} = 1^3 - 1 = 0,$$

$$T_2 = t_{2,1}^3 - t_{2,1} = 2^3 - 2 = 6,$$

...

$$T_{13} = t_{13,1}^3 - t_{13,1} + t_{13,2}^3 - t_{13,2} = 2^3 - 2 + 2^3 - 2 = 12,$$

...

In the same way, the sum of the ranks for the remaining experts is determined;

2) Determination of the total amount of matched ranks

$$\sum_{k=1}^K T_k = 0 + 6 + \dots + 12 + \dots 0 = 36,$$

3) Determination of the sum of ranks for each factor:

$$S_n = \sum_{k=1}^{M_k} R_{kn} \quad (8)$$

$$S_1 = R_{1,1} + R_{2,1} + \dots + R_{k1} + \dots + R_{20,1} = 1 + 1,5 + \dots + 1 = 21,5;$$

$$S_2 = R_{1,2} + R_{2,2} + \dots + R_{k2} + \dots + R_{20,2} = 3 + 4 + \dots + 4 = 76;$$

$$S_3 = 57;$$

$$S_4 = 92,5;$$

$$S_5 = 97;$$

$$S_6 = 77.$$

4) Determination of average values of the sums of ranks for all factors:

$$\bar{S} = \frac{\sum_{n=1}^N S_n}{N} \quad (9)$$

$$\bar{S} = \frac{21,5 + 76 + 57 + 92,5 + 97 + 77}{6} = 70$$

5) Calculation of quadratic deviations of the sums of ranks from their average value:

$$(S_1 - \bar{S})^2 = (21,6 - 70)^2 = 2352$$

$$(S_2 - \bar{S})^2 = (76 - 70)^2 = 36$$

$$(S_3 - \bar{S})^2 = (57 - 70)^2 = 169$$

$$(S_4 - \bar{S})^2 = (92,5 - 70)^2 = 506$$

$$(S_5 - \bar{S})^2 = (97 - 70)^2 = 729$$

$$(S_6 - \bar{S})^2 = (77 - 70)^2 = 49$$

6) Determination of the sum of quadratic deviations:

$$\sum_{n=1}^N (S_1 - \bar{S})^2 = 2352 + 36 + \dots = 3600;$$

7) Determination of the coefficient of concordance according to the formula (3):

$$\omega = \frac{12 * 3600}{20^2 * 6 * (6^2 - 1)} = 0,519$$

8) Determination of χ^2 Pearson criterion by the formula (5):

$$\chi^2 = \frac{12 * 3600}{20 * 6(6 + 1) - 36/(6 - 1)} = 51,9$$

9) Determination of the number of degrees of freedom:

$$m = N - 1 = 6 - 1 = 5$$

10) Determining the tabular value of the Pearson criterion for a given number of degrees of freedom $m = 5$ and 5% significance level:

$$\chi^2_{t} = 31,41;$$

$$\chi^2_{t} = 31,41 < \chi^2_{\text{calc.}} = 51,9$$

The probability of an accidental coincidence of the opinions of experts is small.

4 Conclusion

The method of expert assessments makes it possible to effectively use the experience of highly qualified specialists in the construction industry, which can reduce the time and cost of developing predictable solutions to reduce energy consumption at a construction site when erecting buildings from reinforced concrete, especially at the initial stages in the process of organizational and technological design.

Based on the calculations made, the hypothesis that there is agreement of experts when ranking the factors is accepted as true, to research based on the organizational-technological methodology, mechanization and automation of work in the construction of high-rise buildings [9-20].

The adapted methodology of expert assessments allows, in addition to taking into account the basic indicators of the complexity and duration of technological processes for all types of construction work in the construction of monolithic buildings, to make flexible adjustments to technical decisions taking into account the consumption of fuel and energy resources (total and specific) as part of the project technical and economic indicators in general, as well as as part of the construction master plan and the construction schedule.

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